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AUSTRALIA

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PROVISIONAL SPECIFICATION

Applicant(s):

THE UNIVERSITY OF SYDNEY

Invention Title:

OPTICAL PLANAR WAVEGUIDE DEVICE AND METHOD OF ITS FABRICATION

The invention is described in the following statement:

OPTICAL PLANAR WAVEGUIDE DEVICE AND METHOD OF FABRICATION

Field of the invention

The present invention relates to the construction of a planar optical waveguide devices for the processing of optical signals.

Background of the invention

The utilisation of optical circuits is becoming increasingly important in the transmission of high bandwidth telecommunication signals. Further, fast switching and wavelength selection and filtering are rapidly becoming indispensable components of all optical Dense Wavelength Division Multiplexed (DWDM) networks. Such devices tend to be exceedingly complex and expensive to construct. It would be generally desirable to provide for the simpler mass production of such complex optical devices.

Another very important optical device at the heart of the DWDM systems is a multi wavelength transmitter. Among available candidates for multi wavelength transmitters, are those based on external cavity silica-based laser modules which offer low chirp and greater wavelength stability and control. Unfortunately, such devices often have minimal modulation capabilities. The desirable inclusion of optical signal modulation functions in such modules would enhance their performance and increase the cost effectiveness of fabrication.

Known carrier injection/absorption effects in semiconductors permit switching/modulation to be performed on the required timescale of nanoseconds or less. Existing devices incorporating semi-conductor functionality are typically epitaxially grown or made in monocrystalline semiconductor substrates. Whilst having high modulation/switching performance such devices are relatively expensive to fabricate, suffer high insertion losses and cross talk and are limited in the number of wavelength channels.

Recently, a hybrid solution has been proposed

where integrated semiconductor optical amplifier (SOA) gates which perform switching are integrated on a platform with silica-based waveguides used for signal routing and fibre interconnects [T. Kato et al., Technical Digest of OFC-98, Post Deadline Paper PD3, 1998]. Although this solution combines advantages of fast switching in semiconductors with the versatility of silica-based waveguides, it is still not ideal from point of view of mass manufacturability and cost, since the SOA gates still need to be manufactured on separate chips and then assembled in modules, requiring alignment and wire bonding.

Summary of the Invention

It is an object of the present invention to provide for an integrated optical device whereby integrated silica-based waveguides and semiconductor carrier injection/absorption elements are integrated monolithically.

In accordance with a first aspect of the present invention, there is provided a planar waveguide device for processing optical signals, the waveguide device comprising a semiconductor component monolithically integrated with a silica waveguide structure in which the semiconductor component preferably can include electrical controls alterable so as to modulate an optical signal passing through the silica waveguide structure.

The refractive index of portions of the semiconductor component are preferably altered so as to modulate the optical signal. At least one optical mode propagating in the silica waveguide structure can propagate or interact with the semiconductor component so that the effective refractive index of the mode can be electrically controlled. This allows the semiconductor component to perform optical signal processing.

The semiconductor component can be deposited in the form of a thin film structure before, after or during the formation of the silica waveguide structure. The component can be deposited in an amorphous or

polycrystalline form. A single or multiple semiconductor component can be formed during deposition by in-situ doping of semiconductor material. The semiconductor component can also be formed after the formation of the silica waveguide structure by partial removal of a cladding layer of the silica waveguide device.

The semiconductor component can be formed from hydrogenated amorphous silicon deposited by plasma enhanced chemical vapour deposition.

Alternatively, the semiconductor component can be formed from polycrystalline silicon grown in situ or produced by solid phase crystallisation of amorphous silicon.

The geometry of the semiconductor component and silica waveguide structure and their relative spatial position are preferably determined such that optical signal losses associated with optical mode transmission between the component and structure are preferably minimized.

The formation of any portion of the silica based waveguide formed after formation of the semiconductor component can be formed at temperatures sufficiently low to avoid damaging the semiconductor component. Ideally, hollow cathode PECVD can be utilized for low temperature formation of the silica waveguide structure.

In accordance with a further aspect of the present invention, there is provided an integrated planar waveguide optical detector comprising a semiconductor component monolithically integrated with a silica waveguide structure in which the semiconductor component is utilized to convert an optical signal into a corresponding electrical signal.

The band gap of the semiconductor component can be adjusted to provide photsensitivity at the optical signal wavelength. Preferably, the semiconductor component can comprise substantially Si-H and Ge-H.

In one embodiment, the devices can be formed on a semiconductor substrate including electrical signal

processing circuits formed thereon. The substrate can be formed of silicon.

In one example embodiment the devices, and in particular the waveguide portions, are advantageously constructed utilising a semiconductor material in a semiconductor on insulator configuration.

Brief Description of Drawings

Notwithstanding any other forms which may fall within the scope of the present invention, preferred forms of the invention will now be described, by way of example only, with reference to the accompanying drawings in which:

Fig. 1 illustrates a device constructed in the course of the principles of the present invention;

Fig. 2 illustrates the process of incorporation of the device Fig. 1 in a mark-sidna arrangement.

Description preferred and other embodiments

In the preferred embodiment, as noted previously, the silica-based waveguides and the semiconductor carrier injection/absorption elements are integrated monothically. This results in substantial cost reductions compared to a hybrid integration alternative since batch processing techniques can be utilised throughout the fabrication process.

Turning now to Fig. 1, there is illustrated a scheme with a sectional view of an example device 1 which is formed on a substrate 2 and utilises a semiconductor component 7 which, for example, can comprise thin film amorphous silicon or silicon/germanium p-I-n structure. It is incorporated into a silica based channel waveguide structure so that large and fast phase/aptitude modulation of optical signals in the waveguide 4 can be achieved via a free carrier injection/absorption mechanism.

Previously, it is known to provide modulators in monochrystalline silicon which can be operated at high speeds. Through the utilisation of amorphous silicon structures, the speed of operation can be increased due to the intrinsically small carrier life time in amorphous

material. This allows for an extremely attractive technique for construction of the DWDM modulated sources since the speed of modulation of semiconducted materials is combined with the high functionality and performance of silica-based devices.

Such incorporation of amorphous semiconductor into a silica based waveguide requires the use of a low temperature silica deposition techniques since the high temperature otherwise necessary would destroy both semiconductor properties of the material and p-i-n carrier injecting structures. One form of suitable deposition technique is that outlined in PCT application PCT/AU/96/00563 entitled "A Method and Apparatus for the Construction of Photosensitive waveguides" and in CM Horwitz, S. Boronkay, R. Gross and K.E. Davies, "Hollow Cathode Etching and Deposition" J. Vac. Sci technology AG, at pages 1837 to 1844 (1998) which discloses a low temperature Hollow Cathode-Plasma Enhanced Chemical Vapour Deposition (HS-PECVD) process. The semiconductor component can be formed as a p-i-n structure in amorphous silicon for example by the method described in S. Guha, X. Xu, J. Yang and A. Banerjee "High deposition rate amorphous silicon-based multijunction solar cell" Appl. Phys. Lett. 66(5), PP 595-597, 1995. The utilisation of the low temperature HC-PECVD process disclosed in the aforementioned specification allows for the construction of a silica-semiconductor modulator combination.

As shown in Fig. 1 there is shown one such constructed device, where light propagating in a core 4 of a silica-based channel waveguide interacts with the semiconductor component 7, which is either incorporated in or located sufficiently close to the core 4, so that the effective refractive index of the fundamental optical mode of the waveguide is determined by both the refractive index of silica layers 3, 4, 5 and the refractive index of the semiconductor component 7. When the refractive index of the semiconductor is changed by carrier injection by

applying electrical signal to the electrodes 8, 9, the effective refractive index of the fundamental mode propagating in silica-based waveguide in vicinity of the semiconductor is also changed accordingly. This can be utilized for very fast (on the time scale of minority carrier lifetime in the semiconductor) modulation or switching e.g. by using the induced phase shift in a Mach-Zhender configuration.

Fig. 2 illustrates an example Mack-Zhender arrangement wherein a semiconductor layer 7 is formed over the core 4 of one arm of the two arm Mach-Zhender in the system. By using the semiconductor 7, the refractive index of part of arm 4 is modulated relative to the arm 10 so as to produce a phase shift which in turn results in an intensity modulation between the output arms 11, 13.

Further, alternative applications for utilising the change in the effective refractive index of the fundamental mode can be undertaken. For example, the change in refractive index can be utilised to alter the peak spectral position of a Bragg grating formed in the region of a silica based waveguide where mode refractive index changes are induced by the presence of a semiconductor layer. The shifting of the peak spectral position can in turn provide for the large modulation of a signal or selection between different wavelengths.

In yet another application the refractive index changes induced by the semiconductor in the multimode region of a multimode interference (MMI) device or waveguide array gratings (WAG), can be used for fast wavelength switching between different output ports.

In addition to the carrier injection effect in semiconductors which provides fast changes in refractive index, free carrier absorption effects can also be used for optical signal modulation or attenuation. In this case the driving electric signal determines the intensity (not phase as in carrier injection) of light at the output of the semiconductor interaction region.

In practical realisation of such devices the issues of adiabatic transition between pure silica and silica/semiconductor region of the channel waveguide are preferably manipulated in order to minimise the loss associated with this transition.

In practice, the most suitable type of modulation (carrier injection or absorption) should be experimentally determined for amorphous silicon material produced with e.g. Ultra-High-Vacuum PECVD machine. Carrier injection, as opposed to carrier absorption, has smaller power requirements but at the same time can be off-set by simultaneous thermo-optic effect (which drives refractive index in the opposite direction) unless an adequate heat sink is provided and/or operating current is kept low.

In an alternative embodiment of the present invention, the semiconductor component can be used to convert an optical signal into an electrical signal thus performing a detector function. For that purpose the semiconductor component is designed and fabricated in such a way that it exhibits absorption at the optical signal wavelength. This is different from the previously described application where semiconductor component was used to modulate the optical signal, in which the absorption in the no drive voltage state should be minimal.

The necessary absorption (determined by the semiconductor junction band gap) can be tailored by varying the composition of the semiconductor material. For example, a p-i-n structure based on pure amorphous silicon has little absorption at the 1.5 micron telecommunication wavelength, but codoping with Ge can reduce the band gap and provide the necessary photosensitivity in the infrared.

In practical realisation of such integrated photodetector such issues as its size and back reflections should be addressed. The size can determine the detector capacitance, which in turn determines the maximum achievable bandwidth. High light conversion efficiency will be required to minimise the semiconductor component

size (thus increasing bandwidth). The effect of back reflections can be minimised by either using a dielectric (eg. silicon nitride) antireflection coating or by the angling the waveguide end face on which the semiconductor component is formed.

The semiconductor component for the detector application can be fabricated, for example, by the method described in Hwang SB, Fang YK, Chen KH, Liu CR, Hwang JD, Chou MH "An a-SiH/a-Si, Ge:H bulk barrier phototransistor with a-SiC:H barrier enhancement layer for high-gain IR optical detector" IEEE Transactions on Electron Devices, 40(4), pp721-726, 1993.

Combined with the integrated transmitter modules based on the use of semiconductor component as a modulator, the additional detector function of the semiconductor component can provide for an important synergistic effect. This allows the fabrication of low cost transceiver modules for optical local access networks.

In another variation of the preferred embodiment the silicon substrate is used and the driver circuits for modulator or the amplifier circuits for the detector are fabricated in the silicon substrate prior to the fabrication of integrated silica-based and semiconductor components. This allows for additional cost savings via increase of functionality of each single chip, mass-manufactured by the batch IC techniques. The low temperature technique for fabrication of the silica based planar waveguide component allows for the implementation of this approach.

In yet another embodiment of the present invention some of the waveguide devices can be realised in semiconductor material incorporated into a silica structure. An example of the cross-section of such semiconductor waveguide is shown in Fig. 3. The semiconductor layer 30, which is transparent at the optical signal wavelength, is utilised with the waveguide formed by rib 32 etched into it. The waveguide 32 is enclosed between

silica layers 31, 33. The bottom and top silica layers are used for optical isolation of the waveguide channel from the substrate and surface defects respectively. Conceptually, such structure is used in silicon on insulator (SOI) waveguides fabricated by the "separation by implanted oxygen" (SIMOX) method and subsequent epitaxial regrowth of silicon. This approach has been useful for some applications where tight light confinement (and therefore ulta-compact devices) in high refractive index semiconductor material is desirable. However, this approach involves relatively complicated processing which has an impact on both device yield and cost. Realisation of such structure by conventional thin film technology would eliminate these disadvantages. As an example of this approach, the SOI structure can be made by deposition and patterning of amorphous silicon layer which has similar optical properties to that of crystalline silicon currently used for commercially produced SOI structures. Significant cost reductions and yield improvement of the SOI devices can be achieved by this method.

It would be appreciated by a person skilled in the art that numerous variations and/or modifications may be made to the present invention as shown in the specific embodiments without departing from the spirit or scope of the invention as broadly described. The present embodiments are, therefore, to be considered in all respects to be illustrative and not restrictive.

We Claim:

1. A planar waveguide device for processing optical signals, said waveguide device comprising:

a semiconductor component monolithically integrated with a silica waveguide structure in which the semiconductor component includes electrical controls alterable so as to modulate an optical signal passing through said silica waveguide structure.

2. A planar waveguide device as claimed in claim 1 wherein the refractive index of portions of said semiconductor component are altered so as to modulate said optical signal.

3. A planar waveguide device as claimed in any previous claim wherein at least one optical mode propagating in the silica waveguide structure also propagates or interacts with the semiconductor component so that the effective refractive index of the mode is electrically controlled.

4. A planar waveguide device as claimed in any previous claim wherein said semiconductor component performs optical signal processing on said signal.

5. A planar waveguide device as claimed in any previous claim wherein said semiconductor component is deposited in the form of a thin film structure before, after or during the formation of the silica waveguide structure.

6. A planar waveguide device as claimed in claim 5 wherein said semiconductor component is deposited in an amorphous form.

7. A planar waveguide device as claimed in claim 5 wherein said semiconductor material is deposited in a polycrystalline form.

8. A planar waveguide device as claimed in claim 5 wherein a single or multiple semiconductor component is formed during deposition by in-situ doping of semiconductor material.

9. A planar waveguide device as claimed in any

previous claim wherein the semiconductor component is formed after the formation of the silica waveguide structure by partial removal of a cladding layer of said silica waveguide device.

10. A planar waveguide device as claimed in any previous claim wherein said semiconductor component is formed from hydrogenated amorphous silicon.

11. A planar waveguide device as claimed in claim 10 wherein said hydrogenated amorphous silicon is deposited by plasma enhanced chemical vapour deposition.

12. A planar waveguide device as claimed in any previous claim wherein said semiconductor component is formed from polycrystalline silicon.

13. A planar waveguide device as claimed in claim 12 wherein said polycrystalline silicon is grown in situ.

14. A planar waveguide device as claimed in claim 12 wherein said polycrystalline. silicon is produced by solid phase crystallisation of amorphous silicon.

15. A planar waveguide device as claimed in any previous claim wherein the geometry of the semiconductor component and silica waveguide structure and their relative spatial position are determined such that optical signal losses associated with optical mode transmission between the component and structure are minimized.

16. A planar waveguide device as claimed in any previous claim wherein the formation of any portion of the silica based waveguide formed after formation of the semiconductor component is formed at temperatures sufficiently low to avoid damaging the semiconductor component.

17. A planar waveguide device as claimed in claim 16 wherein hollow cathode PECVD is utilized for low temperature formation of the silica waveguide structure.

18. An integrated planar waveguide optical detector comprising a semiconductor component monolithically integrated with a silica waveguide structure

in which the semiconductor component is utilized to convert an optical signal into a corresponding electrical signal.

19. A detector as claimed in claim 18 wherein the band gap of said semiconductor component is adjusted to provide photsensitivity at the optical signal wavelength.

20. A detector as claimed in claim 18 or claim 19 wherein the semiconductor component comprises substantially Si-H and Ge-H.

21. An apparatus as claimed in any previous claim wherein said apparatus is formed on a semiconductor substrate including electrical signal processing circuits formed thereon.

22. An apparatus as claimed in claim 21 wherein said substrate is formed of silicon.

23. An apparatus as claimed in any previous claim wherein a portion of the device is constructed utilising a semiconductor material in a semiconductor on insulator configuration.

24. An apparatus as claimed in claim 23 wherein the waveguide channels are formed in a semiconductor on insulator configuration.

25. A method for forming a device as claimed in any previous claim.

Dated this 18th day of March 1999

THE UNIVERSITY OF SYDNEY

By their Patent Attorneys

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Fellows Institute of Patent

Attorneys of Australia

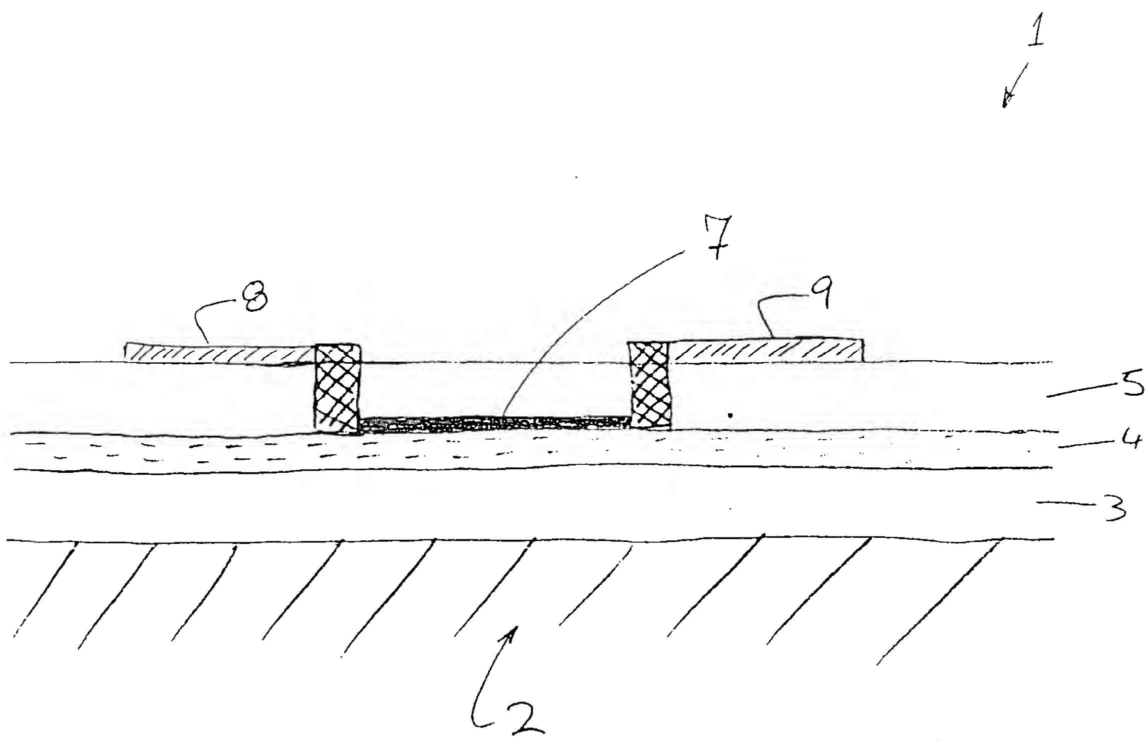


Fig. 1

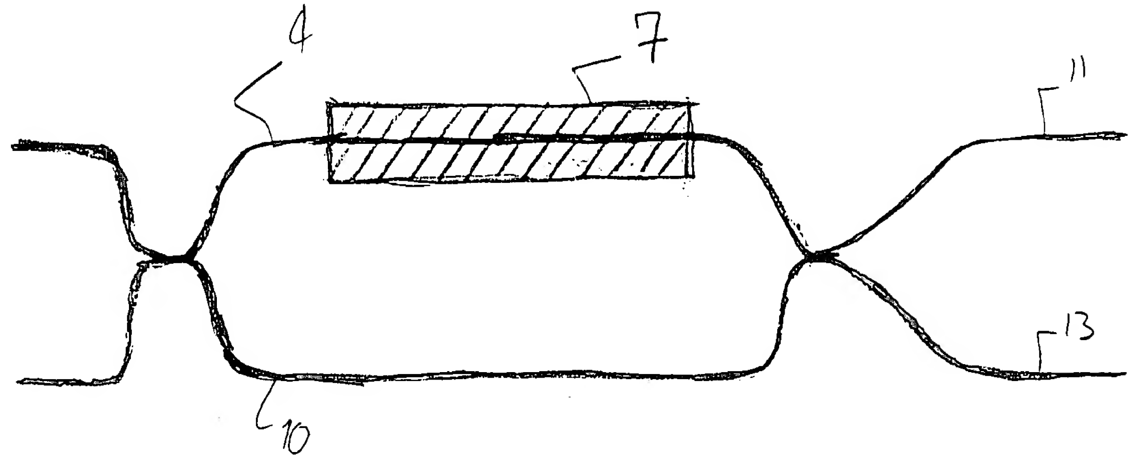
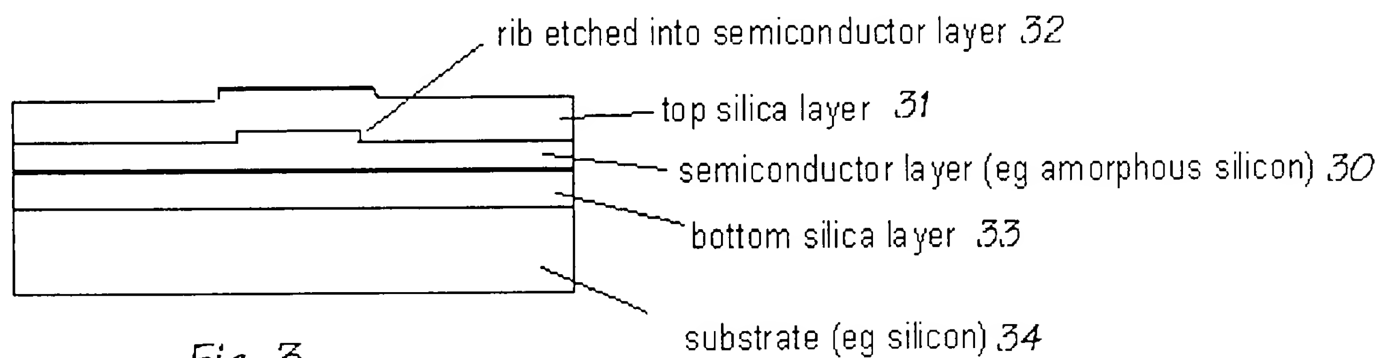


Fig. 2


rib etched into semiconductor layer 32
top silica layer 31
semiconductor layer (eg amorphous silicon) 30
bottom silica layer 33
substrate (eg silicon) 34
Fig. 3

ABSTRACT

A planar waveguide device for processing optical signals, the waveguide device comprising: a semiconductor component monolithically integrated with a silica waveguide structure in which the semiconductor component preferably can include electrical controls alterable so as to modulate an optical signal passing through the silica waveguide structure. An integrated planar waveguide optical detector is also providing including a semiconductor component monolithically integrated with a silica waveguide structure in which the semiconductor component is utilized to convert an optical signal into a corresponding electrical signal.